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Effect of Teaching Metacognitive Learning Strategies on Performance in General Chemistry Courses

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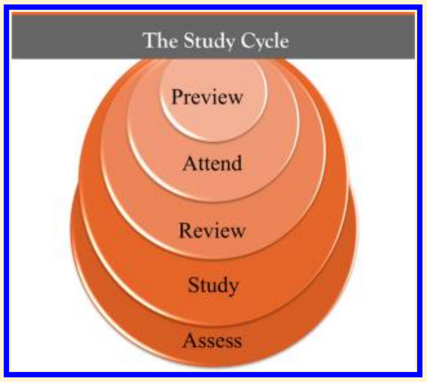
Ⓢ *Supporting Information*



ABSTRACT: College students often find general chemistry to be a very challenging rite of passage on their way to degrees in various science, technology, and mathematics disciplines. As teachers, we make efforts to simultaneously patch gaps in students' prior knowledge and instill valuable learning strategies and sound study habits. In this paper, we describe effective metacognitive learning strategies for students in general chemistry courses. Many students experience difficulty because they are focused on memorizing facts and formulas instead of understanding concepts and developing problem-solving skills. However, students can be successful if they are taught how to shift their efforts from low-level to higher-order thinking. We present outcomes from a 50 min lecture on learning strategies presented to a population of nearly 700 science major first-year students after the first examination. The average final grade for the students who attended the lecture was a full letter grade higher than that of those who were absent, while the performance on the first examination was not statistically significantly different for the two groups. Student survey response data indicated that the students who attended the lecture changed their behavior as a result of gaining new information about learning. Statistical analysis of the results was performed using the ANCOVA approach.

KEYWORDS: *First-Year Undergraduate/General, Chemical Education Research, Learning Theories, Student-Centered Learning, High School/Introductory Chemistry*

FEATURE: Chemical Education Research

■ INTRODUCTION

The major impetus behind this study was the unacceptably high attrition rate in general chemistry (GC) classes at Louisiana State University (LSU). This problem—common across the nation—is particularly disturbing because general chemistry is a gateway for many different STEM (science, technology, engineering, and mathematics) degree programs. Students who fail to complete required GC courses are unlikely to continue in a STEM degree program, a fact with negative implications for the rate at which the United States produces STEM professionals.[1] Clearly, this trend needs to be reversed to meet the ambitious goal set by President Obama for the United States to have the highest proportion of students graduating from college by 2020. The nation's colleges and universities must do their part to increase students' success. Improving the performance of students in introductory STEM courses, especially gatekeeper courses such as general chemistry, is crucial to accomplishing this.

In order to enroll in the general chemistry I (GC-I) class at LSU, students must have completed college algebra and have completed or be coenrolled in trigonometry or calculus. The general chemistry sequence (I and II) is taken primarily by first-year students who enter the university with a wide variety of mathematics and science backgrounds, a range of (dis)interest in the subject of chemistry, and a broad spectrum of learning strategies and study habits. While students' confidence at the start of the semester tends to be high, the first exam often reveals problems ranging from inadequate time spent studying to spending too much time in an unproductive way. Without intrusive intervention, students often fail to recover from the shock of receiving a low score on their first college chemistry exam and end up receiving a grade of D or F, or withdrawing from GC-I.

Many studies focus on updating teaching methods and enhancing the science learning experience. Some of these methods focus on the following:

- Accounting for multiple learning styles[2−4]
- Targeting student misconceptions[5]
- Assessing students' ability to identify and process information using advances in modern technology[6−9]
- Aiming at increasing student involvement in the learning process[10−14]
- Endeavoring to obtain meaningful feedback from students in an effort to maximize time and effort spent on teaching the most challenging concepts[2]
- Assessing students' knowledge[15−19]

Clearly, the effort to facilitate meaningful and effective teaching and learning in the sciences is not limited to chemistry.[20−24] Recent proliferation of first-year enhancement programs,

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known as boot camps, reflects efforts of many universities to enhance student success and retention rates in science.[25,26]

Teaching Students about Metacognition

Whereas improving teaching methods will positively impact student performance, we have focused our efforts on teaching students how to help themselves by giving them the tools necessary to develop meaningful learning skills with long-lasting effects. These skills include, but are not limited to, retaining information, applying information to new situations, and skillfully and creatively solving problems. The key to this approach is metacognition or "thinking about thinking". We foster students' application of metacognition to their learning in GC-1.[27]

Metacognition has been shown to be an essential element in students' efforts to attain deeper understanding of concepts in chemistry and become expert problem solvers.[28−31] In this section, we describe several learning strategies that directly use metacognitive skills. Each skill or strategy aims to reveal to the student at which level of Bloom's taxonomy he or she is learning.[32] Moreover, each skill or strategy is based on specific cognitive science or learning support research.[33] The following descriptions explain why each strategy works:

> *Paraphrasing and rewriting* lecture notes is an effective way for students to demonstrate understanding of the material. In order to put information in one's own words, it is necessary to actively construct meaning from text, and to access what one already knows about the topic. It helps students connect new information to what they already know, and it forms cues for retrieval of the information for future use.[34]
>
> *Working homework problems without using an example* as a guide helps students obtain practice in performing tasks that will be required on exams, that is, solving problems and answering questions without the help of any external aids. If students have never solved problems on their own, without the aid of an example or, worse yet, using a Web site that provides answers to textbook problems, they will not develop problem-solving skills. But when they take the time to learn the concepts so well that they can solve problems on their own, they will confidently perform similar tasks in a testing situation.
>
> *Previewing* the material before lecture gives students an overview of what will be covered and primes the brain for learning details. When students have an anticipatory mindset fostered by previewing, they are more engaged in lecture and retain more information.
>
> Whereas faculty members know the efficacy of *group study* for increasing learning, many students do not understand its importance. However, students are much more likely to study in groups when they learn *why* it is important. When students work in groups, they are more likely to evaluate each other's thinking and correct misconceptions expressed by others. Additionally, hearing how others think differently about a topic can inform and increase a student's own understanding. When students work in groups, they are more likely to be metacognitive about how they approach information.[35]
>
> *Pretending to teach* information (to a live or imagined audience) is valuable because it allows students to discover concepts that they *thought* they understood but did not fully understand, and to do so *before the examination*, when there is still time to learn it.

Below, we review Bloom's taxonomy and the Study Cycle, two important features of the intervention subsequently described.

Teaching Bloom's Taxonomy

There are different levels of learning, from simply memorizing information verbatim to developing independent problem-solving skills. Most students are not aware of this and spend the majority of their effort on memorization tasks. One particularly effective way to present the different levels of learning to students is to discuss Bloom's taxonomy (Figure 1), which represents a hierarchy of learning levels.[36−39] Commonly, successful high school performance can be accomplished while operating at the two lowest levels, namely, *remembering* and *understanding* (to answer such questions as "Is HCl a strong or a weak acid?"), while graduate school demands mastery at the two highest levels (*evaluating* and *creating*). When introduced to the taxonomy, first-year students readily see that they have been operating at the lowest levels, whereas the GC-1 course requires them to at least be at *applying* and *analyzing* (e.g., to "predict pH at the equivalence point in a titration of a weak base with a strong acid").[40,41] Once aware of Bloom's taxonomy, the students are prepared to monitor their learning levels.

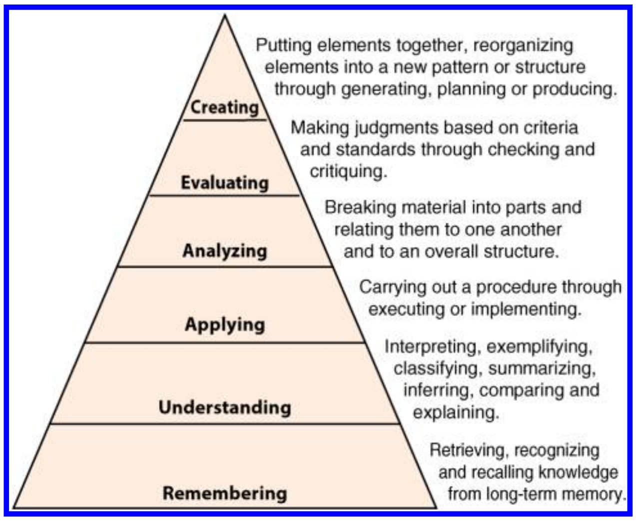

Figure 1. A revised Bloom's taxonomy of educational objectives.[39]

The Study Cycle

After students have learned about Bloom's taxonomy and have become aware of the need to learn at higher levels, we teach a specific strategy to promote this progress, namely, the Study Cycle (Figure 2). The Study Cycle is adapted from the Preview−Learn−Review−Study system developed by Frank L. Christ.[42] The Study Cycle gives students a very concrete strategy that they can implement to improve their study skills and monitor their learning strategies.[42]

We explain to students that the sequence of "preview, attend, review" facilitates exposure to the class material three times in short succession, typically within fewer than 24 h. Akin to watching a movie trailer and getting mentally prepared for the type of movie (e.g., drama vs comedy), even a rudimentary preview, which involves a visual scan of a chapter in the course textbook or lecture handout (if available in advance) and taking notice of the titles of sections, subsections, bold faced and italicized print, figures and figure captions, comments on margins, and so on, is enough for a student to gain added

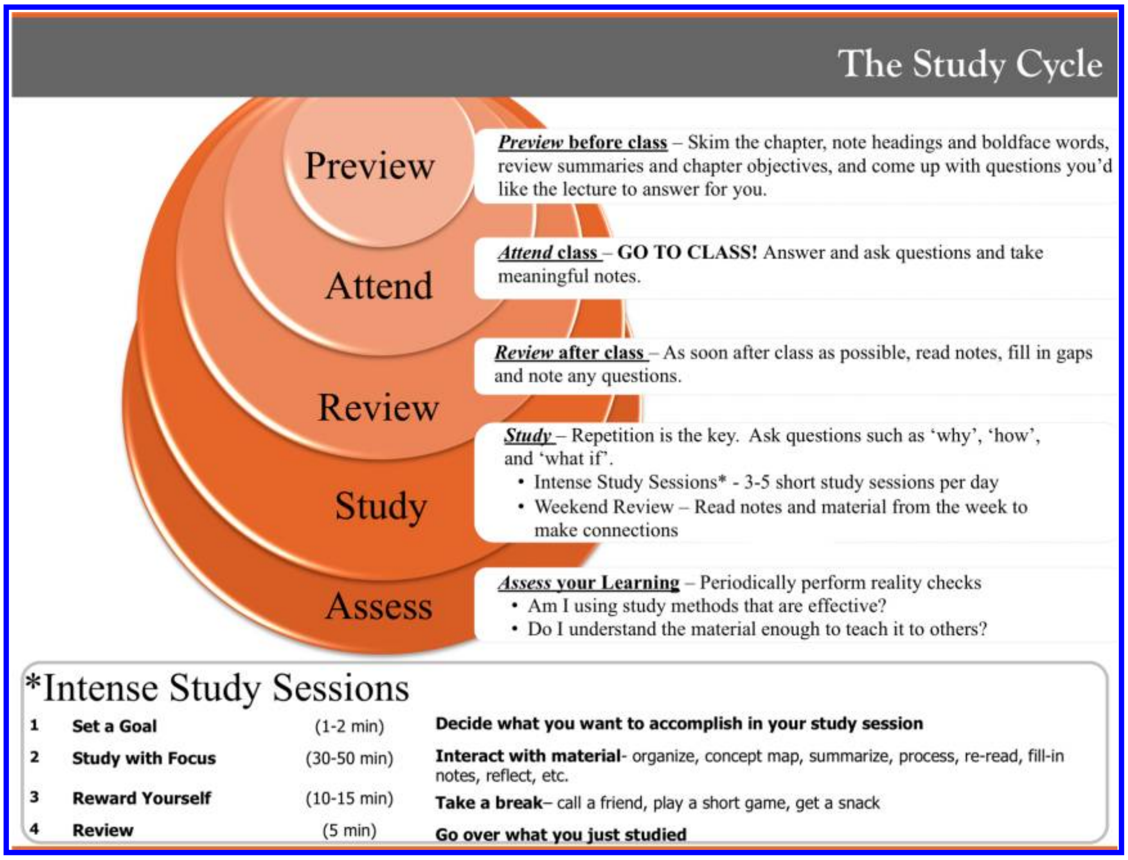

Figure 2. The Study Cycle as presented to the Louisiana State University students seeking advice from the Center for Academic Success.

benefit from attending class. By previewing, students become primed for pattern recognition, may experience more frequent spikes of interest in the material being taught, and even have more courage to ask questions in class because they are more comfortable with the instructor's discourse. The subsequent review, ideally done right after the class, allows students to quickly determine areas of overlap between lectured material and textbook information, revisit concepts and numerical problems covered in class, and establish whether assistance will be necessary and plan accordingly. Strategic placement of bite-size study periods allows the material to be transferred to long-term memory and eliminates the need to cram before exams. Daily exposure to the material by completing one Study Cycle before the next cycle begins also establishes a routine and proper study habits, which ultimately lead to better outcomes on exams. We acknowledge that it often takes considerable effort to convince students—who initially worry that applying the Study Cycle will take too much time—to try this learning strategy. Students are equally reluctant to solve problems without looking up solved examples. In the end, however, students recognize that, to become expert problem solvers by exam time, they must develop confidence in their own ability to generate problem-solving ideas and to independently carry out required procedures. The discussion about metacognition teaches students that learning is a *process* and that it requires time: time to make mistakes and learn from them; time to see how one problem is similar to and different from another (analysis); and time for the material to gel.

■ THE INTERVENTION

The intervention was performed in GC-I classes taught by one of us (E.C.) in the Fall of 2010 and 2011. It provided the learning strategies information in one 50 min lecture that was presented by another one of us (S.Y.M.). The learning strategies lecture aimed to accomplish three goals: (i) Explain to students why the skills that they found effective in high school no longer work at the university; (ii) offer students a smorgasbord of metacognitive learning tools to replace or supplement those used in high school; and (iii) secure from the students a commitment (via a short writing exercise) to use those tools in the weeks following the presentation. To accomplish the first goal, Bloom's taxonomy was presented; students were then asked to identify which learning level they mastered in high school and which level they believed they would need to master in order to succeed in college. To achieve the second and third goals, the wide variety of metacognitive strategies presented to the students was made even more attractive by several success stories and testimonials from their peers. In our experience, many first-year students do not believe that their high school study habits and learning skills are deficient because nothing in their experience would suggest that this is the case. They have their A grades in high school chemistry to prove it! Therefore, talking about college-style learning is often pointless unless the students experience first-hand that their previous strategies do not yield the same positive results when they are applied to college learning tasks. Consequently, the 50 min lecture on learning strategies was strategically placed shortly after the scores for the first of four semester exams were made known to the students, approximately four weeks into each of the Fall semesters.

In Fall 2011, we compiled two lists of learning strategies. The first list was based on student responses to the question: "*What strategy will you use for the next three weeks?*" Students received an incentive of 5 bonus points for participating in this writing exercise at the end of the learning strategies lecture. The second list consisted of strategies our students actually tried and found useful; this information was obtained via an online exit survey administered at the end of the semester, and students provided their responses voluntarily. The PowerPoint presentation for the learning strategies session is provided in the Supporting Information.

Academic support for this intervention, as well as many additional services aimed at improving students' performance, was provided by the Center for Academic Success (CAS).[43] In fact, students who wish to receive help in becoming better learners can do so regardless of whether or not they participated in this project. However, relatively few students take advantage of these resources without encountering them in a class session. Students involved in this project were more directly exposed to the services the CAS provides and were actively encouraged to use them throughout the semester.

■ RESULTS

In Table 1 we summarize and rank student responses provided in the writing exercise (left column) and the exit survey (right column). Statistical analysis of students' performance follows this summary. Responses in Table 1 show that students initially appeared to recognize the need to (i) modify their study habits and (ii) incorporate effective learning strategies, such as various parts or the entirety of the Study Cycle. The exit survey shows that students embraced a range of metacognitive learning strategies.

Table 1. Learning Strategies Declared and Found Useful by Students for Fall 2011

2011 Ranking	Percentages for Initial Strategies and Commitments from 508 Individual Responses[a]		Percentages for Strategies Deemed Useful from 477 Individual Responses[b]	
1	33	Employ the whole Study Cycle[c]	57	Review past exams
2	24	Do homework earlier	32	Review[c]
3	20	Aim at 100% understanding	32	Study for exams earlier
4	19	Study more	30	Read textbook more
5	19	Read textbook more	29	Use SI[d] more
6	15	Use chapter or concept maps	25	Do homework earlier
7	13	Review	24	Aim at 100% understanding
8	10	Use SI[d] more	24	Use intense study sessions[e]
9	9	Preview	23	Study more
10	6	Do homework without looking up solved examples	18	Study in a group

[a]Responses submitted as a writing exercise. [b]Responses submitted online as an exit survey. [c]Part of a Study Cycle.[42] [d]Supplemental instruction (SI) sessions are provided by CAS for courses with a large number of D, F, and W grades.[44] [e]Intense study sessions may be incorporated into the Study Cycle[42] or used as a separate strategy.

At the conclusion of each Fall semester, we were encouraged to see that the final average course grade for the students who attended the 50 min learning strategies lecture was one entire letter grade higher than that for those who did not; see Table 2.

Table 2. Final Average Course Grades in the General Chemistry I Course in the Fall 2010 and 2011

	2010		2011	
Intervention Status	*N*	Final Average (Letter Grade)[a]	*N*	Final Average (Letter Grade)[a]
Attendees: treatment	428	81.5 (B)	473	81.6 (B)
Nonattendees: control	167	72.6 (C)	195	70.4 (C)

[a]A 10-point grade system was adopted: A ≥ 90% > B ≥ 80% > C ≥ 70% > D ≥ 60% > F.

Clearly, a closer look—including an in-depth statistical analysis of the collected data—was justified. Student performance data were collected and the Fall 2011 data were analyzed for statistically significant differences between students who attended the learning strategies lecture and those who did not.

Statistical Analysis

Detailed course performance and demographic data were collected during the 2011 Fall semester. These data were statistically analyzed to determine whether participation in the interactive learning strategies lecture had an impact on student performance in GC-I. The participants in the study were 668 first-year and transfer students. The overall course grade consisted of the following components: four semester exams (4 × 150 points each), one final exam (250 points), and homework (150 points), for a total of 1000 points. Students also had several opportunities to earn extra credit (bonus) for such items as in-class clicker responses (30 bonus points), take-home and online quizzes (25 bonus points), review bonus questions added to select homework assignments (15 bonus points), and the participation in the 50 min session on learning strategies and study skills (5 bonus points). Of the 668 students enrolled in the course, 473 (71%) attended the learning strategies session. The dependent variable for the study was the total number of points obtained in the course. Several adjustments were made: first, the 5 bonus points added for those that attended the learning strategies session were retracted; second, total score points included performance on the first exam, which was administered prior to the treatment. To adjust for this, exam 1 was removed from the total score. The primary research question was as follows:

> *Did participants who attended the learning strategies session (the attendees) perform differently in the course (as measured by the total course points) in comparison to those who did not attend the session (the nonattendees)?*

To address this question in a purely scientific manner, the ideal approach would be to randomly assign students to treatment (participation in the seminar) and control conditions. However, this was not feasible in the current instance, as our overall goal was to present effective learning strategies to as many students as possible without denying anyone the equal opportunity to benefit from learning the material well. It was our opinion that any selection process imposed by us would be unfair and possibly morally questionable. Nevertheless, our collective experience with this course over the years has led us to believe that the processes governing attendance on a given day are largely random with regard to variables that impact GC-I outcomes. To assess the tenability of this hypothesis, data for

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both the attendees and nonattendees were collected on a number of variables either known or hypothesized to be related to success in introductory chemistry courses.[45,46] These data—on which comparisons were made for the two groups—included the following (the codes in parentheses correlate with variables in tables below and in the Supporting Information):

- ACT Mathematics Score (ACT_MATH): Students with higher ACT_MATH scores tend to score better than those with lower scores.
- High School Academic Grade Point Average (HS_GPA): Students with higher HS_GPAs tend to perform better than those with lower averages.
- Campus Housing (CAMPUS): First-year students who live in campus housing tend to do better academically than those who live off-campus.
- Hours Carried (HOURS): In general, the more credit hours carried, the lower the academic performance.
- Transfer Status (TRANSFER): Transfer students tend to do less well academically than those who are not transfer students.
- First-Generation College Status (FIRST_GEN): Students who are the first in their family to attend college tend to do less well academically.

In addition to these variables, data were also collected on demographic variables: gender, ethnicity, age, and enrollment year.

To address the research question, analysis of covariance (ANCOVA) was utilized. The statistical package SPSS 20 was used for all analyses. Performance on exam 1 was used as a covariate. This was considered appropriate because this exam was administered prior to the treatment and had a strong relationship with total score in the course. The analysis proceeded in the following manner. First, data were examined for normality, presence of outliers, homogeneity of variances, a basic linear relationship of the covariate with the dependent variable (the total number of points obtained in the course), and equality of slopes for treatment and control groups used in the study. The results of these tests are presented in the online Supporting Information. The measure of effect size used for this study is η^2.

Table 3 presents summary statistics for comparisons between attendees in the learning strategies session and nonattendees. These comparisons were focused on the question of whether or not it was reasonable to conclude that the two groups of students were comparable with respect to these indicators. The results show that there were few statistically significant differences in the groups on any of the indicators considered, and when minor differences did occur, the related measure of effect size (Cohen's d) was in the small range (less than 0.25).[47] The two groups were also compared with respect to their performance on the pretreatment examination administered in the first weeks of the course, that is, exam 1. As shown in Table 3, there were no significant differences between these groups, with the exception of high school grade point average. Even here, however, the difference had an effect size measured by Cohen's d of only 0.35, in the moderate range. Further, as can be seen in Table 3, the means were identical up to the ten's place, indicating that the significance was due to the small variability in the high school grade point averages for this population. Taken together, these results suggest that, prior to exam 1, and hence, prior to the intervention, any differences between the attendees and nonattendees in the learning strategies session were most likely owing to chance processes and were unrelated to the primary focus of this study, addressing a possible criticism that somehow the learning strategies lecture was attended primarily by the better students.

Table 3. Comparisons of Treatment and Control Groups

Variable	Group	N	Mean	SD	t-Test Results
ACT_MATH	Control	179	25.838	3.34	1.49
	Treatment	449	25.39	3.37	
HS_GPA	Control	167	3.32	0.43	−4.06[a]
	Treatment	431	3.48	0.40	
CUM_HRS	Control	184	19.79	16.20	1.12
	Treatment	462	18.31	11.80	
AGE	Control	187	18.70	0.97	0.24
	Treatment	465	18.70	1.27	
EXAM_1	Control	175	102.37	29.80	−0.33
	Treatment	467	110.90	25.60	
FIRST-GEN	Control	172	0.41	0.49	0.67
	Treatment	441	0.38	0.49	
CAMPUS	Control	187	0.52	0.50	1.76
	Treatment	465	0.60	0.49	
TRANSFER	Control	187	0.09	0.29	1.67
	Treatment	465	0.05	0.23	
Gender	Control	187	0.43	0.49	−0.95
	Treatment	465	0.47	0.50	

[a]Statistically significant at the 0.05 level.

These results were followed up with an ANCOVA, in which the primary independent variable was participation in the learning strategies session and the covariate was exam 1. An examination of these data indicated that the distribution of total scores had a negative skew, reflecting the fact that some examinees did not complete all score components in the course and received a grade of 0 for each "missed" component. For example, some students did not take all four exams and received a 0 for the exams they did not take. This phenomenon was more prevalent in the control group than in the treatment group. One way of adjusting for the negative skew was to transform the data. We found a transformation recommended by Tabachnick and Fidel[48] to be effective at removing the skewed distribution:

$$Y = \sqrt{\text{maximum score} + 1 - \text{observed score}} \tag{1}$$

The resulting distribution did not deviate substantially from normality and showed some, but not dramatic, departures from homogeneity. The final check on assumptions for these data was the assumption of equal slopes. This was not found to be problematic. See the online Supporting Information for results of these tests.

The results presented in Table 4 show that both the covariate (exam 1) and treatment indicator were significant. The partial η^2 value for the treatment indicator was 0.097, indicating that participation in the treatment explained roughly 10% of the difference in total points awarded after exam 1. The difference was in favor of higher achievement for those who attended the learning strategies session.

■ CONCLUSIONS

Based on the results presented in this study, and on the collective experience of the authors, it appears that college students who do not have the requisite learning strategies to succeed in general chemistry can be taught these strategies in as little as 50 min. Based on interviews with thousands of students

Table 4. ANCOVA Results for Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df[a]	Mean Squares	F Values	Significance	Partial η^2 Values
Exam1	5833.002	1	5833.002	429.125	0.000	0.394
Treatment/control	996.648	1	966.648	71.115	0.000	0.097
Error	8957.643	659	13.593			
Total	168825.620	662				

[a]Dependent variable: final examination.

over the past ten years, one of us (S.Y.M.) has determined that there are several reasons why a rapid and dramatic increase in student performance is possible. First, students in general chemistry are quite motivated to perform well because many of them are aspiring to careers in the health professions. Therefore they are ready to try new strategies when the strategies are presented as based on cognitive science research. Second, when students learn about Bloom's taxonomy, which almost none of them have seen before, they understand what faculty members mean by higher-order thinking. If students have never been explicitly taught that there is more to learning than memorization, they have no way of knowing how to develop higher-order thinking skills. Third, when students are provided with concrete strategies, such as using the Study Cycle and working homework problems without using an example as a guide, they find it easy to begin implementing new behaviors to reach the higher levels of learning required to do well in general chemistry. And finally, when students start using the strategies and experience greater understanding and success, they are motivated to continue, and their performance continues to improve. In our experience, the method of delivering learning strategies presented here is well received in large classes, which are prevalent in undergraduate education, especially at large public universities. Students appreciate receiving the information. One student wrote on the course evaluation form:

> *Without these strategies, I probably would have gotten a C in chemistry. You showed us [...] a way to get an A in the class and I knew that was going to be my only way to achieve that A. I was planning on just studying before the test. But when you stressed how important it was to preview and review and study 2 hours a day or so, I was in shock, but I followed the guideline and got myself an A. So, I would like to thank you, because without these strategies, I probably would have done terribly in chemistry.*

RECOMMENDATIONS

Below we offer the following recommendations for instructors who wish to improve student learning.

- Give the first course examination (or quiz) as early as possible (within the first two weeks, if possible) so that students find out early that their previous learning strategies (mostly memorization) will be insufficient at the college level.
- Provide a learning strategies class session after students have the results of the first examination (or quiz). Use this session to teach students about Bloom's taxonomy, metacognition, the Study Cycle, and effective ways to do homework without using examples as a guide.
- Do not judge students' potential on their initial performance. Instead, encourage them to persist in the face of initial failure, using newly learned metacognitive learning strategies.
- Communicate individual student improvement (without names) to the entire class as a way to motivate all students to implement the strategies.

In taking these actions, we communicate to students that we believe in their ability to succeed and are invested enough in their success to teach them specific learning strategies. We also recognize the need to periodically remind students to use learning strategies and continuously provide them with motivation to consistently use these strategies throughout the semester. The extent to which the students are willing to implement the strategies, and their subsequent success, may surprise you as much as it surprised us.

ASSOCIATED CONTENT

Supporting Information

Complete PowerPoint presentation of the learning strategies lecture; details of statistical analyses; additional figures and tables. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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